LIGO

Data Acquisition, Diagnostics & Controls (DAQ)

Technical Status

Annual NSF Review of Advanced LIGO Project

April 11 - 13, 2012

Rolf Bork, CIT

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LIGO

DAQ Functions

- Provide a global timing and clock distribution system to synchronize all realtime control and data acquisition.
- Provide a common Control and Data System (CDS) infrastructure design and standards for use in all aLIGO subsystem controls.
  - » Real-time applications development tools and code library
    - – Including “hard” real-time operating system, I/O drivers and inter-process communications.
  - » Computer and I/O standards
- Provide all software necessary to synchronously acquire and archive data.
- Provide all computing and networking hardware as necessary to collect data from the various subsystems, format the data and write the data to disk.
- Provide a standard set of diagnostic tools for use in all control subsystems, including ability to:
  - » Inject arbitrary waveforms into realtime control systems
  - » Set and acquire data from defined testpoints on demand
  - » Distribute both diagnostic data and acquired data channel to operator stations
  - » Provide data visualization and analysis tools in support of operations and commissioning.

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DAQ Functions (Continued)

- Provide computers, I/O hardware and software for the acquisition of Physical Environment Monitoring (PEM) data.
  - » New interfaces for existing PEM sensors
- Computers and infrastructure software for the Diagnostic Monitoring Tools (DMT)
  - » Specific application software provided by LSC members
- Control room computers and associated networking, including a common set of operations support software.
- Provide off-line test and development systems for both sites

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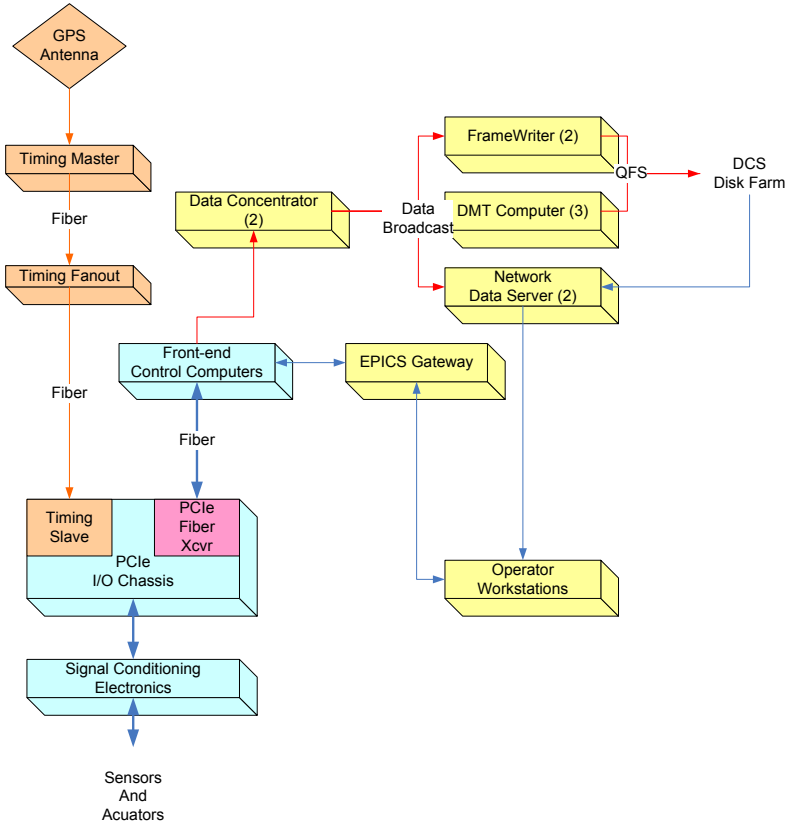
DAQ System
Data Acquisition Requirements

- Provide a hardware design and software infrastructure to support real-time servo control applications
  - » Deterministic to within a few µsec.
  - » High performance to support servo loop rates from 2048Hz to 65536Hz
  - » Built-in diagnostic and data acquisition features
- Acquire and record up to 15MBytes/sec continuously from each interferometer.
  - » 'Fast' data channels at rates from 256 to 32768 samples/sec (Up to 3000/IFO)
  - » 'Slow' data channels at up to 16 samples/sec, with up to 70K channels per interferometer
- Provide capabilities to acquire (but not record) an additional 15MB/sec of diagnostic data.
- Write data in LSC/VIRGO standard Frame format to disk system provided by Data and Computing System (DCS).
  - » Provide local disk to allow up to two weeks of data storage
- Provide an internal data distribution system to communicate diagnostic and acquired data to operator stations and Diagnostic Monitoring Tool (DMT) computers.

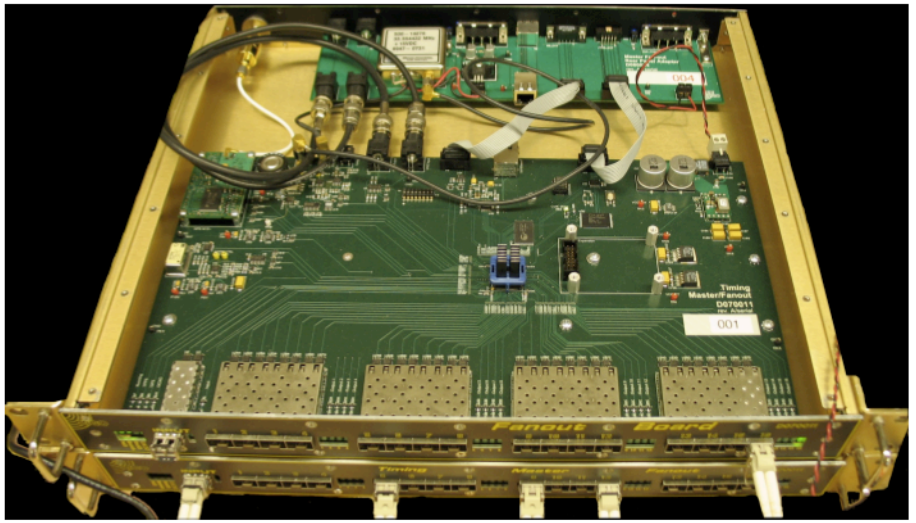
DAQ System Design Overview

- Timing system provides clocks to PCI Express (PCIe) modules in I/O chassis.
- PCIe modules interface to control computer via PCIe fiber link.
- Control computer acquires data and transmits to DAQ data concentrator (DC) via network.
- DC assembles data from all controllers and broadcasts full data blocks every 1/16 second.
- FrameWriter computers format data and write to disk (32sec. data frame)
- Network Data Server (NDS) provides data on demand either live or from disk.

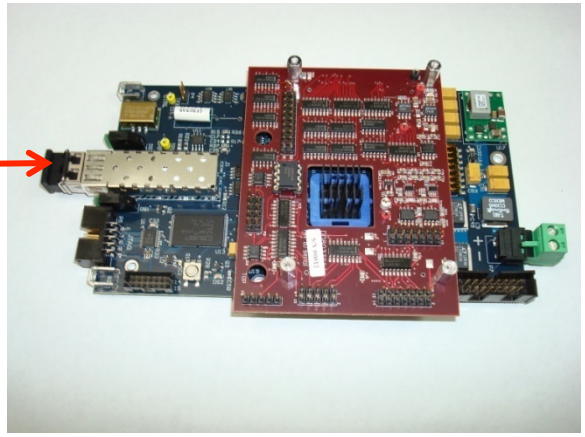


Timing Distribution System (TDS)

- Contracted to Columbia Univ. for manufacture and test after a joint development effort. Design described in the journal *"Classical and Quantum Gravity" under Imre Bartos et al., 2010 Class. Quantum Grav. Vol. 27, No. 8, 084025*



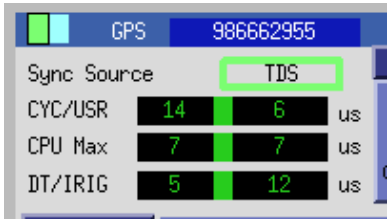
IRIG-B Timing Fanout
Provides accurate time information to computers.



Timing Slave provides accurate clocks At 65536Hz to ADC/DAC modules.

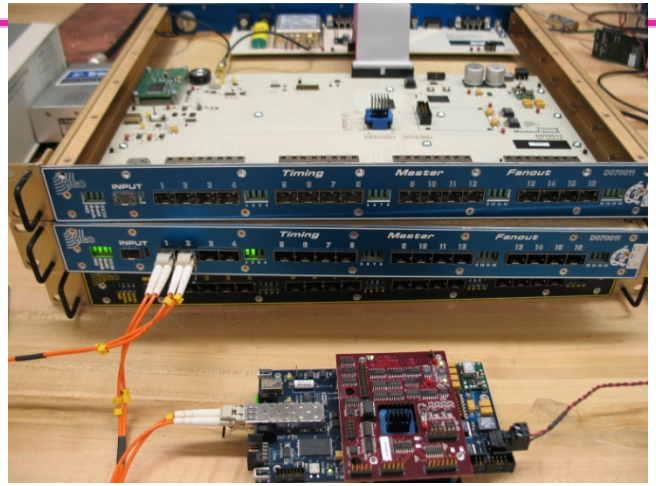
TDS
IRIG-B Distribution Unit

- IRIG-B system used to provide time information, in GPS seconds, to DAQ and control computers.
  - » Includes standard timing slave card to get time information from TDS.
  - » Outputs IRIG-B standard time code
    - – DC Level Shift format
  - » Commercial IRIG-B Receiver modules in computers for accurately setting time in GPS seconds.
  - » Time accuracy to better +/- 1 µsec.
  - » Second source of system time verification, along with duotone signal acquired from timing slave in I/O chassis.

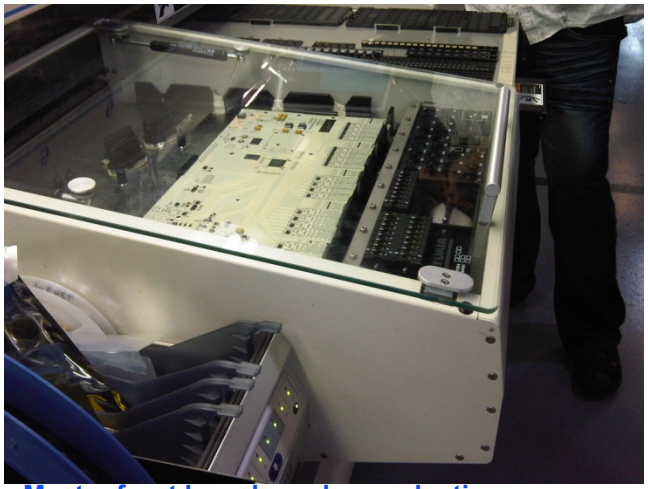


Timing Distribution System Status

- Major components for all IFO have been delivered
  - L1/H2 systems installed.
  - H1 installation in progress.
- Remaining deliveries should be complete by June, 2012:
  - Timing comparators – in test.
  - 4 additional IRIG-B fanout units – in production.



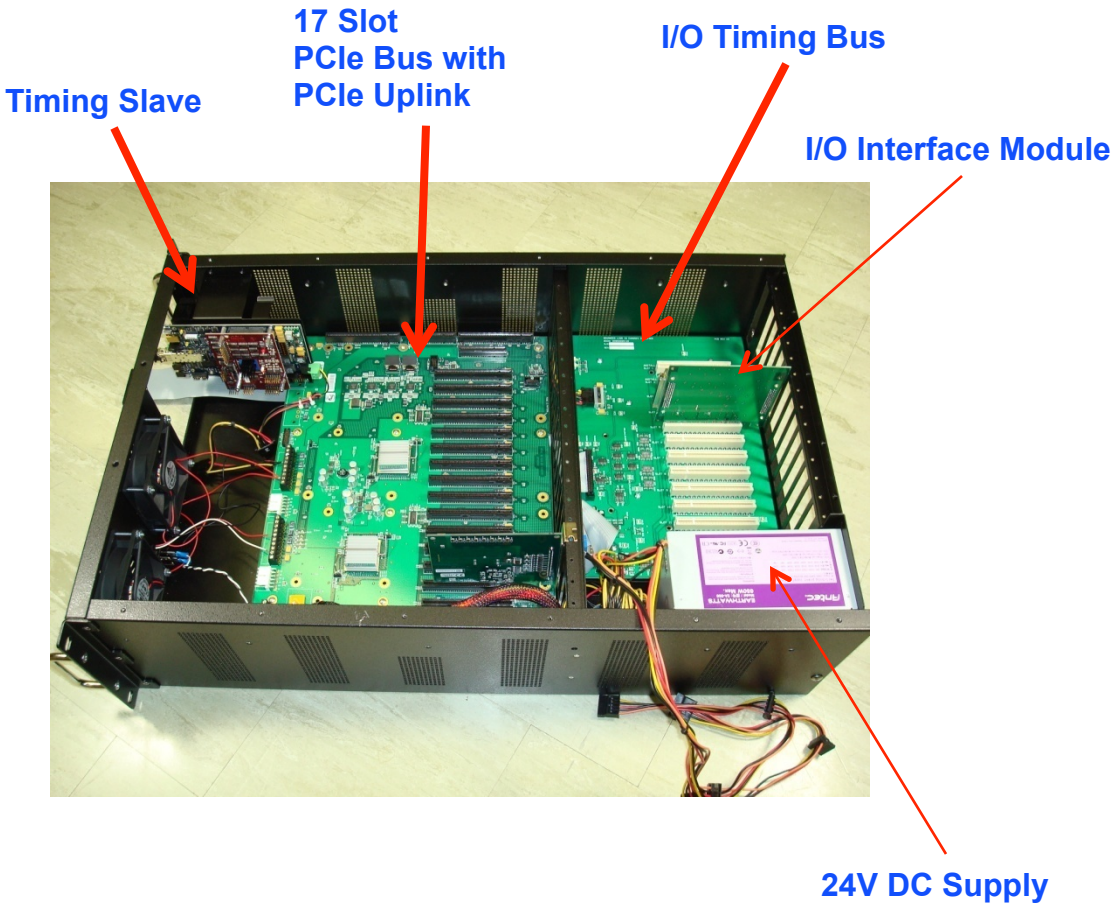
Slave-DuoTone pair being tested at Columbia



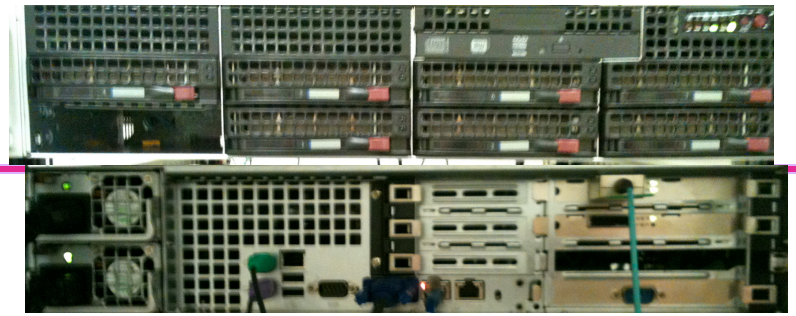
Master front boards under production

CDS Standard PCI Express I/O Chassis

- Commercial PCIe expansion motherboards.
- Custom I/O timing and interface backplane.
- I/O interface modules provide timing and interface between PCIe module connectors and field cabling.
- Two fiber optic links.
  - To timing distribution system via timing slave module.
  - To computer, via fiber optic PCIe link.



CDS Standard Computers



- Supermicro X8DTU-F Motherboards
  - » Fulfills BIOS PCI-e card mapping and real-time stability requirements
- Single Xeon X5680 processor with six cores at 3.33GHz
- Up to 4 full height + 1 half-height PCIe slots
- Two GigE Ethernet ports
  - » Separate EPICS/DAQ networks
- No disk drives installed in computers used for real-time control
  - » Operated as diskless-node from central boot server
- Operating Systems
  - » Gentoo with Linux kernel 2.16.34, plus LIGO RT patch
  - » Ubuntu Linux for CDS servers and other non-real-time computers

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Networking

- Ethernet backbones for most applications
  - » GigE switches with fiber uplinks from end stations
  - » GigE switches with 10G uplink options for corner station
    - – 10G uplink for DAQ and video connections
  - » 10G switches for DAQ Broadcasts
- Low latency networks for real-time data communications.
  - » Initial LIGO type reflected memory (for long runs to end stations)
  - » PCIe network, employing reflected memory software (corner station computers)

PCI Express (PCIe) Real-time Control Network

- Low Latency (1.25usec)
- High speed (10Gbit/sec)
- Cable or Fiber connections
  - CX-4 cable to 3 meters
  - Multi-core fiber to 100 meters
- Stackable 10 port Switches
- Reflected Memory Mode
  - Data broadcast to same memory location on each computer on the network.

Corner to End Station Real-time Control Network

- Loop topology
- Low Latency (700nsec/node)
- High speed (2Gbit/sec)
- Fiber connections
  - Up to 10km
- Bypass Switch provided at each location
- Reflected Memory
  - Data broadcast to same memory location on each computer on the network.

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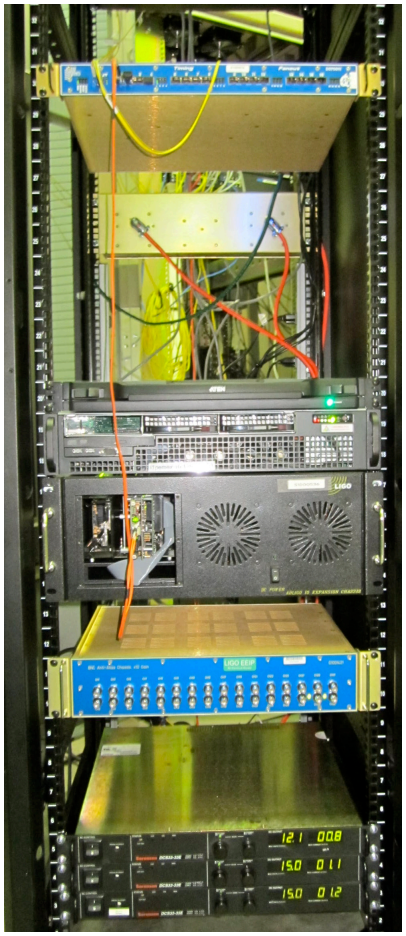
Networking – Progress

- All Ethernet switches have been procured and delivered for all three interferometers.
  - » All network switches have been configured for L1 and H2.
  - » H1 switches are being installed/configured.
- All real-time networking equipment procured and delivered.
  - » Systems installed and running at both sites.

Physical Environment Monitoring Infrastructure

- For aLIGO, PEM system will provide control as well as DAQ
  - » On-line Adaptive Filtering and feed-forward control.
- One computer + 1 I/O chassis at each station and at corner station.
- Re-use existing PEM sensors
- Up to 128 channels of ADC + 8 channels of DAC
  - » I/O connections via AA/AI chassis with BNC connections.
- Progress
  - » Computers, I/O chassis and ADC/DAC modules have all been procured and delivered.
  - » 9 of the 12 AA Chassis have been built and tested.
  - » LLO End Station system under test ----------→



DAQ
Computing / Storage Equipment
(All Delivered and Installed)

- Data Concentrator (DC) (2)
  - » Collects data from all real-time control computers and broadcasts to 10GigE network.
  - » One unit on-line, second hot backup
- FrameWriter (2)
  - » Receive data from DC
  - » Format data into LVC standard Frame format
  - » Write data to disk
    - – Local
    - – Data Analysis group disk farm
- Network Data Server (NDS) (2)
  - » Provides real-time or stored data on request to various control room software tools
    - – NDS clients also developed for Perl, Python and Matlab
- Two computers running Solaris operating system to connect disk systems via QFS.
- 24 TByte Local Disk

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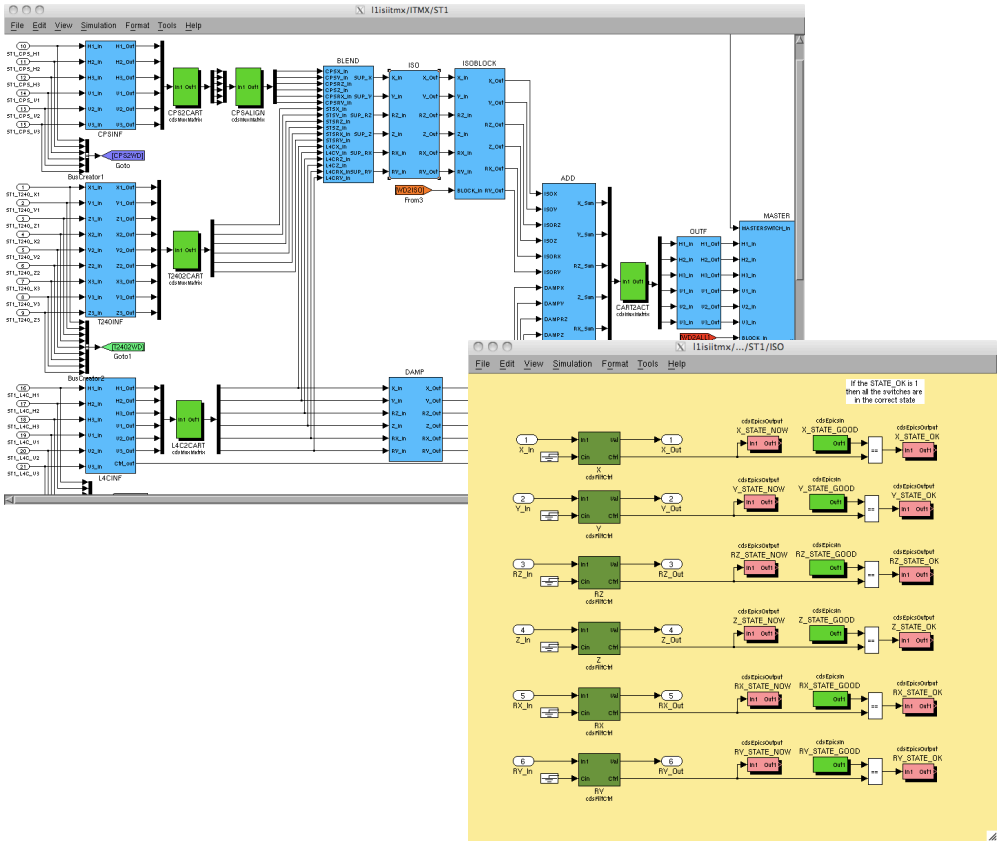
Control Room and Global Diagnostic Systems

- iMac computers w/additional monitor chosen as the standard configuration for operator stations.
  - » Ubuntu Linux Operating System
- Two, dual CPU computers, similar to real-time control computers, in place for Global Diagnostic Monitoring Tool (DMT) applications.
  - » 24TByte disk drive provided for storage of DMT information.
- All equipment is in-house and undergoing installation/test.

Software
Real-time Application Support

- Continued refinement of graphical tool for real-time code generation (“RCG”).
- Allows control application development and documentation without having to know a programming language.
- Allows programming staff to concentrate on development and test of common code modules.



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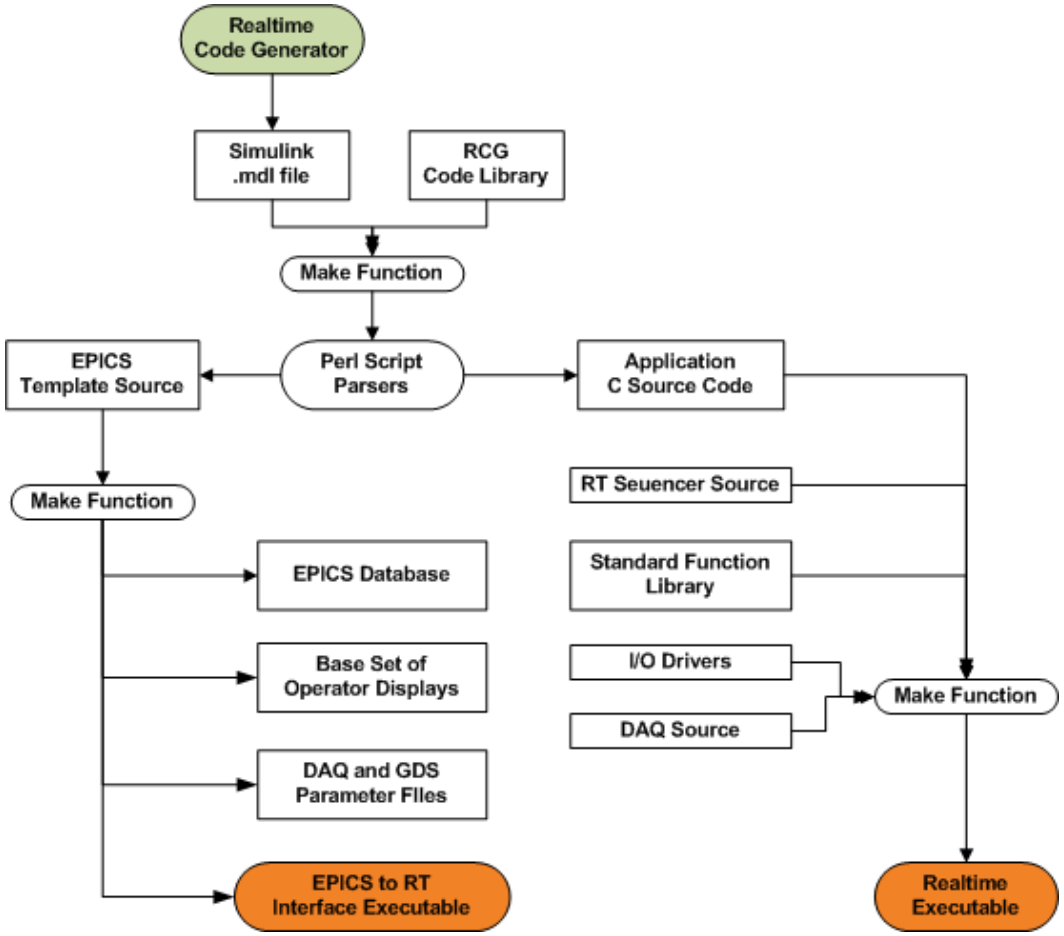
Software
Real-time Application Build Process

- Build and save RCG model.
- make 'modelName'
  - Perl scripts parse the model file to determine signal connections and code flow
  - Perl scripts generate EPICS and real-time source code.
  - Compiler is invoked to link common code libraries and produce real-time and EPICS executable software.
- make install
  - Moves executables to target directories for load onto real-time computers.
  - Channel descriptor files generated for use by DAQ and GDS
  - Basic set of operator displays generated.



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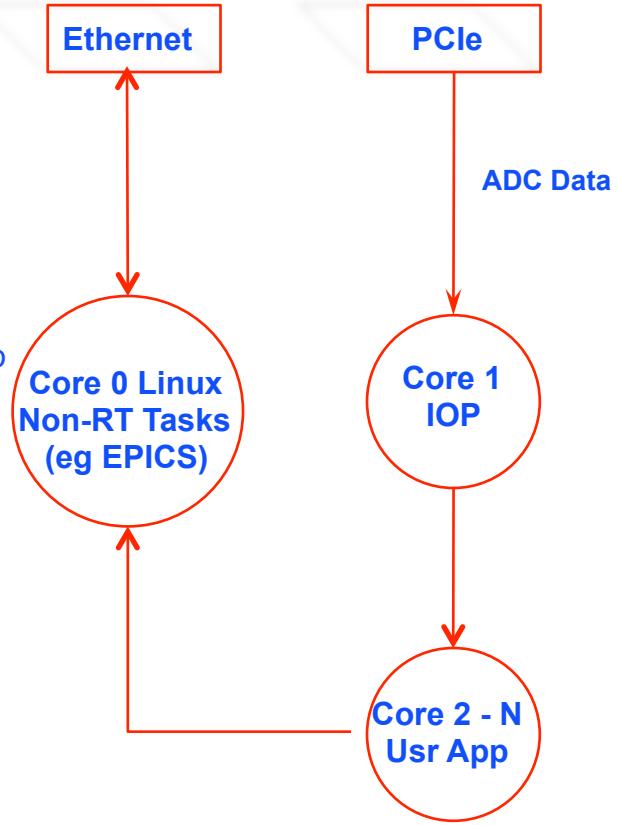
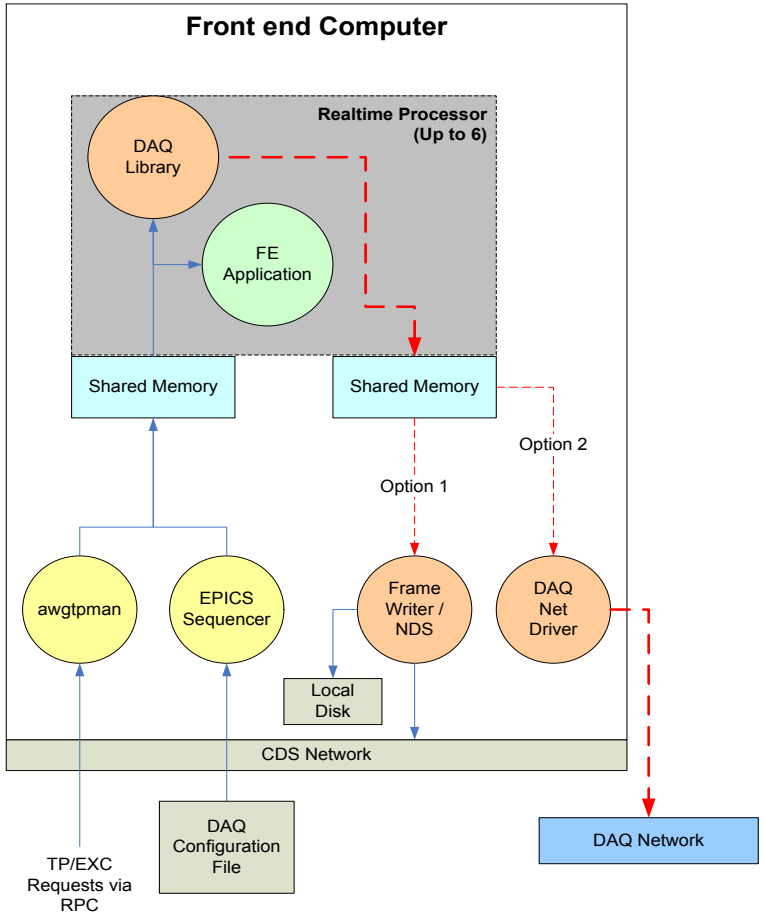
Real-time Core and Patch

- aLIGO Real-Time (RT) code not “traditional”
  - » No pre-emptive operating system scheduler
  - » No interrupts, semaphores, priorities, ensuing context switching, etc.
- Each RT app locked to its own CPU core
  - » Using custom patch to Linux kernel “play dead” routine
    - – Notifies Linux scheduler that CPU is going down and unavailable for interrupts/task assignment.
    - – Inserts RT app code instead of Linux idle routine.
    - – Removal of RT app brings the CPU “back to life” and reconnects to Linux as a useable resource.
  - » RT code runs in continuous loop
    - – Triggered by arrival of ADC data in local memory (polling or MONITOR/MWAIT CPU instructions)
      - ADC modules set up to automatically transfer data to computer memory on clock trigger
    - – Never switched out ie always resident on stack, in cache, memory
- For each RT computer, there is a special case model called an Input/Output Processor (IOP)
  - » Controls startup timing and synchronization.
  - » Maps and initializes all of the PCIe I/O interfaces
  - » Triggers and monitors user applications.
  - » Always running, allowing user apps to come and go, as necessary



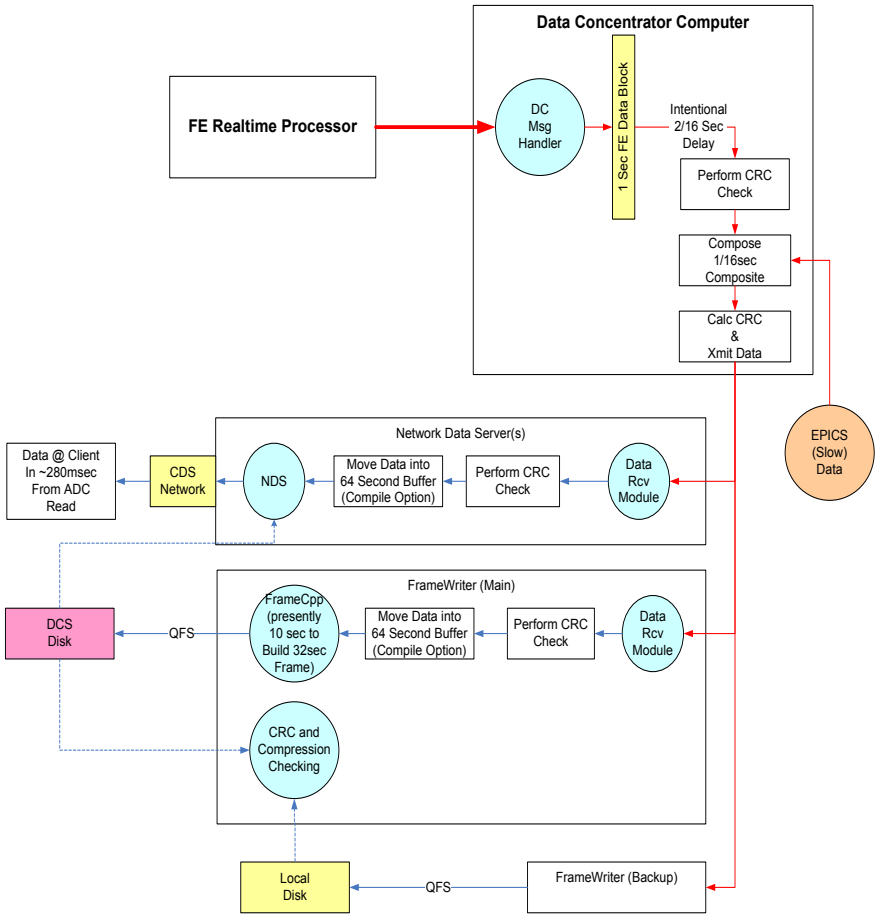
DAQ System
Front-End Software Design

- A common DAQ library is compiled into each FE application.
- Acquires data at user defined rates and transmits data as 1/16sec data blocks:
  - » For archive, as described in a DAQ channel configuration file.
  - » Test point and excitation channel data on demand
    - – As requested via the arbitrary waveform generator/ test point manager (awgtpman)
  - » Supports aggregate (DAQ+TP) data rate of 2MB/sec per FE processor
  - » CRC checksums and timestamps sent with all data blocks
- Supports various configurations
  - » (1) Data to FrameWriter/NDS software on same computer via shared memory
    - – Allows a complete stand-alone system to support various subsystem test stands
  - » (2) Data to shared memory, with separate network software
    - – Supports multiple FE applications on same computer
    - – Relieves RT front end code from network error handling and other possible delays



DAQ System
Backend Software Design

- Data Concentrator
  - » Collects ‘fast’ data from all FE computers via dedicated network
  - » Collects ‘slow’ (EPICS) data via CDS network
  - » Broadcasts combined data to upstream computers as 1/16 sec data blocks on to 10Gb Ethernet
- FrameWriter
  - » Format data into standard LIGO Frame using FrameCpp library, with data compression.
  - » Write data, via QFS, to DCS disk farm (32 second data file)
- Network Data Server (NDS)
  - » Provides live and archived data feeds, on request, to CDS operator stations



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Software Status

- "Final" code version tested and released.
  - » Any new code change requests / bug fixes are to be part of commissioning and operations activities.
- "Line by Line" code review in progress by team not involved in the code development.
  - » Additional outside review planned.
- In process of completing/updating documentation necessary to meet system acceptance requirements.

NSF Review 2011 Concerns

- Concern:
  - » Cyber-security, particularly as it pertains to remote access to LIGO control/DAQ systems.
- Action Taken:
  - » Continuing to work with LIGO cyber-security staff on issues / solutions.
    - – Presently have a two tier authentication system in place, with access provided to a limited set of staff.
    - – In process of implementing and testing “one time use” password system.
    - – Working to develop a method for the site operator to provide final approval for remote logins.

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DAQ System Summary

- Software Development
  - » Complete soon, pending final reviews.
- Equipment Procurement
  - » Complete
- Installation
  - » L1/H2 systems complete and operational.
  - » H1 system installed; cabling and network setup in progress. Anticipate system will be operational by end of April 2012.